Envisioning a Neutrino Program for 2005 - 2030

(with analogies to the Fermilab Collider program of 1985 – 2009)

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(some of this is a personal viewpoint)

My purpose is to provoke discussion and provide some graphic descriptions which can help us to “sell” the NOνA experiment to various constituencies.

The NuMI beam turns on at the beginning of 2005

- U.S. taxpayers, DOE Office of Science, Fermilab, the NuMI Project, the MINOS Collaboration have sweat blood to get this on the air.

- The return on this investment will be hugely enhanced if the NuMI beamline can be used for additional experiments.

- NOνA is such an experiment.
  - adds high efficiency for ν_e detection via low-Z calorimetry
  - goes off-axis to get more ν interactions at 2 GeV
  - will get improved sensitivity as proton intensity increases

This is like the Tevatron Collider Program ~ 1987

- First collisions seen Oct 13, 1985
- But this turned into a PROGRAM because the luminosity of the accelerator kept increasing

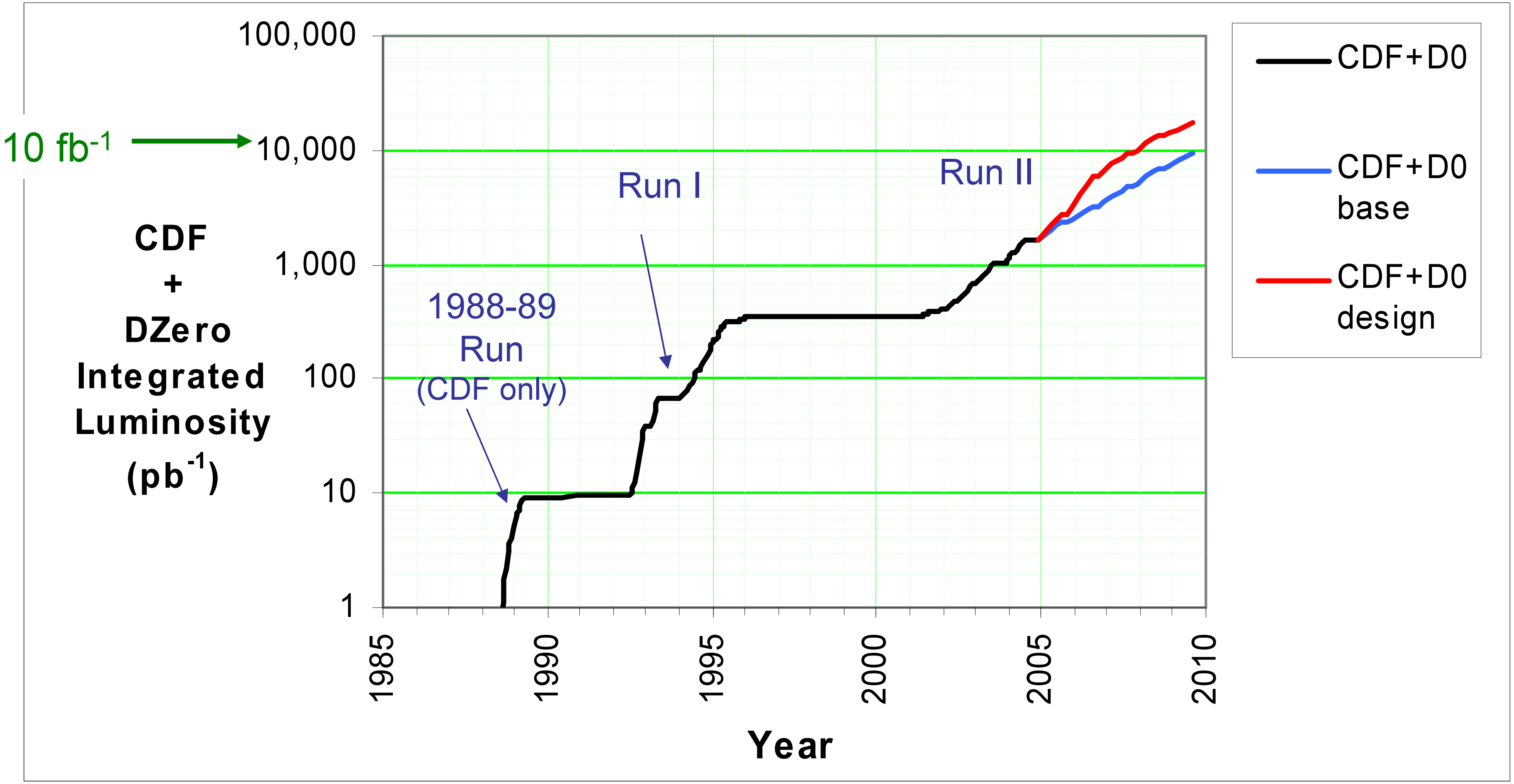
NuMI / MINOS Is about here →

• 10^{25} $cm^{-2}sec^{-1}$ in 1985,	23 event demonstration
• 10^{29} in 1987,	Engineering run (74 nb^{-1} integrated luminosity)
• 10^{30} in 1988-89,	First physics (10 pb^{-1} integrated luminosity)
• 10^{31} in 1992	Run I = 2 * 183 pb^{-1} (DZero Detector & CDF silicon)
• 10^{32} today	Run II (added DZero solenoid & silicon)

  - It's this several <u>orders of magnitude</u> luminosity increase that made the program
    - the factors of 2 in detector upgrades and number of detectors were important but not the driving force

- **There is a similar opportunity in neutrino physics**

Collider Luminosity History



- **Integrated Luminosity doubles 14 times in 21 years (1988-2009)**
  - **(2^{14}=16,384), Integrated Luminosity advances by 3^{+} orders of magnitude**

- **The original 87 CDF collaborators grew to 1500 total at CDF + DZero**

Luminosity in a Neutrino Experiment is slightly different

- Unlike colliders, it's not all due to the accelerator, since

  Number of events seen

  = interaction cross section(σ) * Luminosity

  = (σ_ν)* (protons on target) *(mass of detector, **M**)

  - Yes, the cross section is small in neutrino physics
  - Yes, the physics now aims at detecting small oscillation fractions as well
  - Yes, some of the investigations will likely use anti-neutrinos where the cross sections are even smaller
  - But by the way, the cross sections for discovery at colliders (including LHC) aren't large either
  - If these experiments were easy, we would have done them years ago

- NuMI * MINOS will start at 1 – 2 (x 10^{20}) pot * 5 kT
  - So a "new" unit of integrated luminosity is 10^{20} pot*kT
  - And MINOS starts with 5 - 10 x 10^{20} pot*kT in 2005

Neutrino Luminosity

- Actually, it's a little more complicated:
  Number of events seen =
  (σ_ν)*(prot on target)***fiducial** mass*(detection **efficiency**)

  - **Fiducial mass** typically 80 – 85% of constructed mass
    - But only 45% @ Super Kamiokande (SK), so it makes a difference

  - What about detection **efficiency** ? It depends on the physics process.
    - ν_μ, ν_e, or ν_τ detection ?
    - Quasi-elastic efficiency? Quasi-elastics with an observed recoil proton?
    - Neutral currents?
    - Colliders have different efficiencies for different processes also
      - Trigger efficiency, offline tagging efficiency, …

    - A 25 year neutrino view may lead in strange & unanticipated directions?
      - So, I will ignore efficiency in the context of this big picture overview

  - AND, $\underline{\sigma_\nu}$ **is proportional to** $\mathbf{E_\nu}$
    -
    -
    - next slide

E_ν is related to baseline length, L

- Everybody wants to operate at the L/E most appropriate to oscillations from one neutrino species to another
  - For constant L/E, a long baseline L allows larger E, therefore a larger neutrino interaction cross section and more events

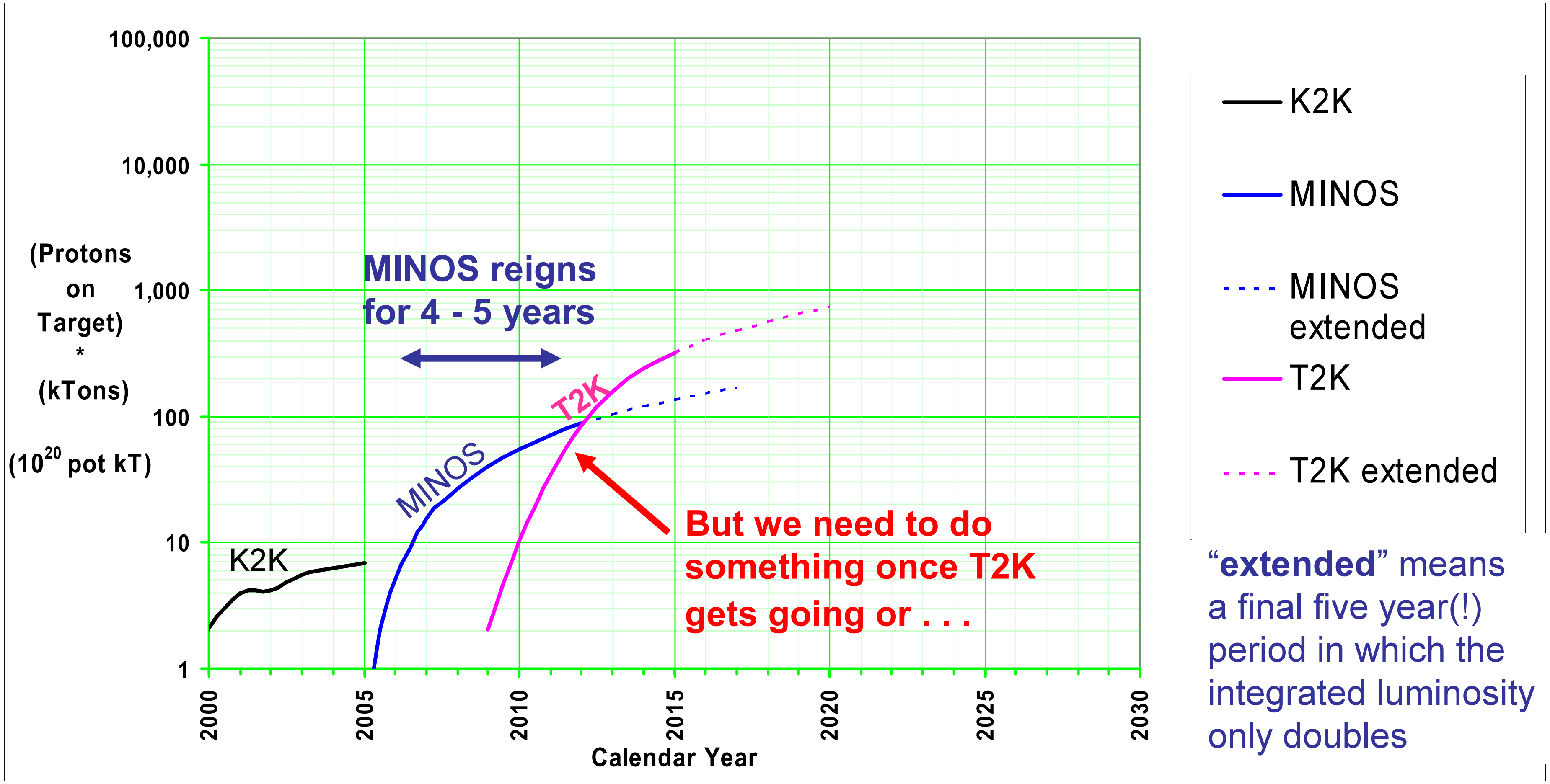
- NOνA proposes to sit at 810 km

- Also, longer baselines give larger matter effects on ν_e in the earth's crust, allowing a better window on the neutrino parameters
  - 30% effect at NOνA (810 km), only 11% at JPARC (295 km)

- So unlike colliders, the highest energy accelerator is NOT the whole ballgame.
  - Instead, **Long Baseline L is the measure of interest**
  - and **(baseline length)**$^{\sim 1.15}$ is kind of like Collider energy
    - **The US has the longest baseline (NuMI) and we should exploit it**
      - Japan is stuck at 250 - 295 km
      - Europe is currently consumed with the LHC and is looking toward a very short baseline program in the Frejus tunnel.

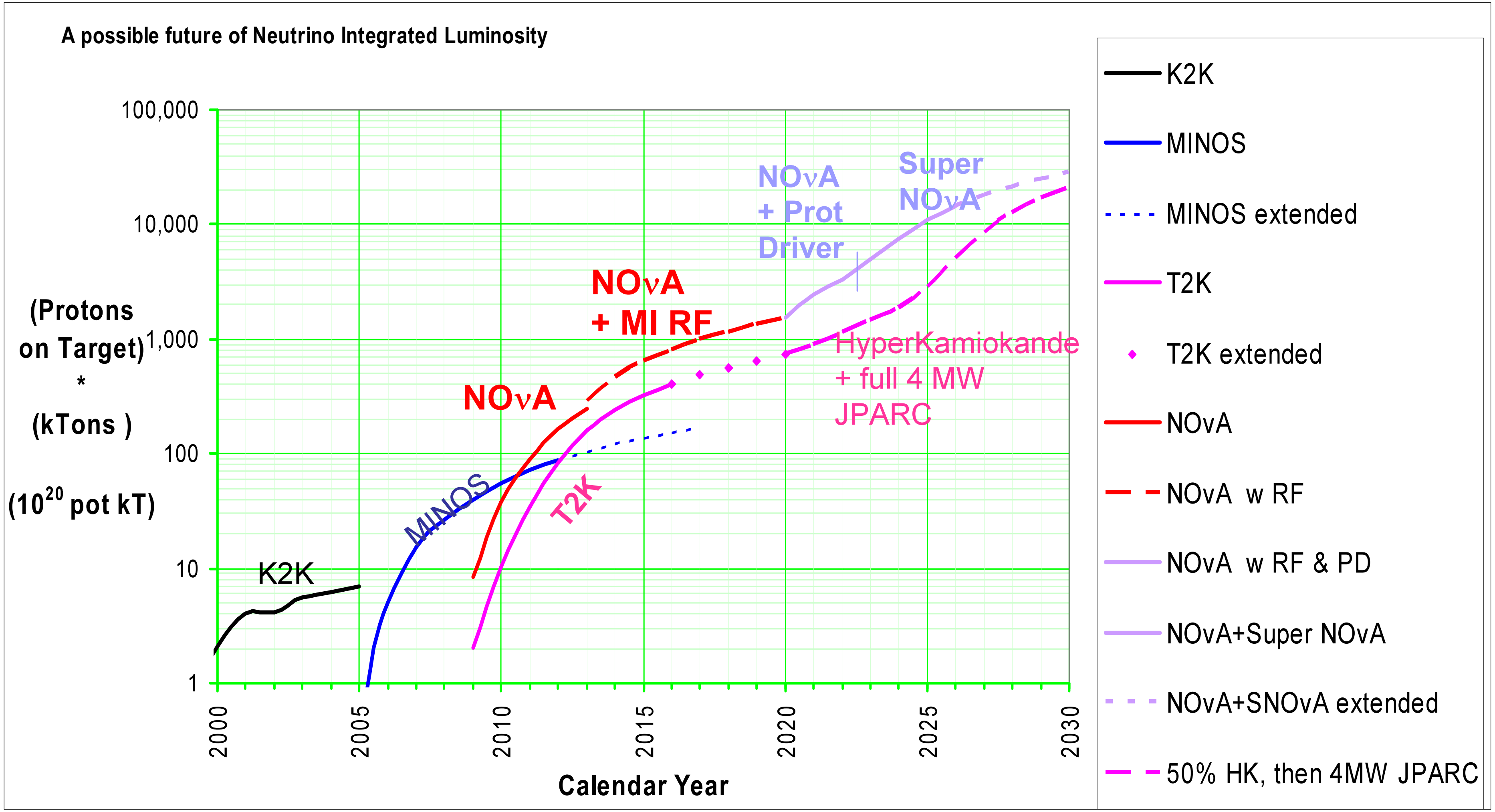
“Planned Program” Luminosity

- pot*kT vs time for the programs in place / under construction
  - Includes fiducial volumes
  - Ignores detection efficiency
  - **Multiplies pot*kT by (L / 810 km)**



NOνA is the "something" to add !

- 25 kT proposed, but assume start with a partial detector in early FY09
  - Assume twice the protons in FY12 with a Main Injector RF upgrade by 2012

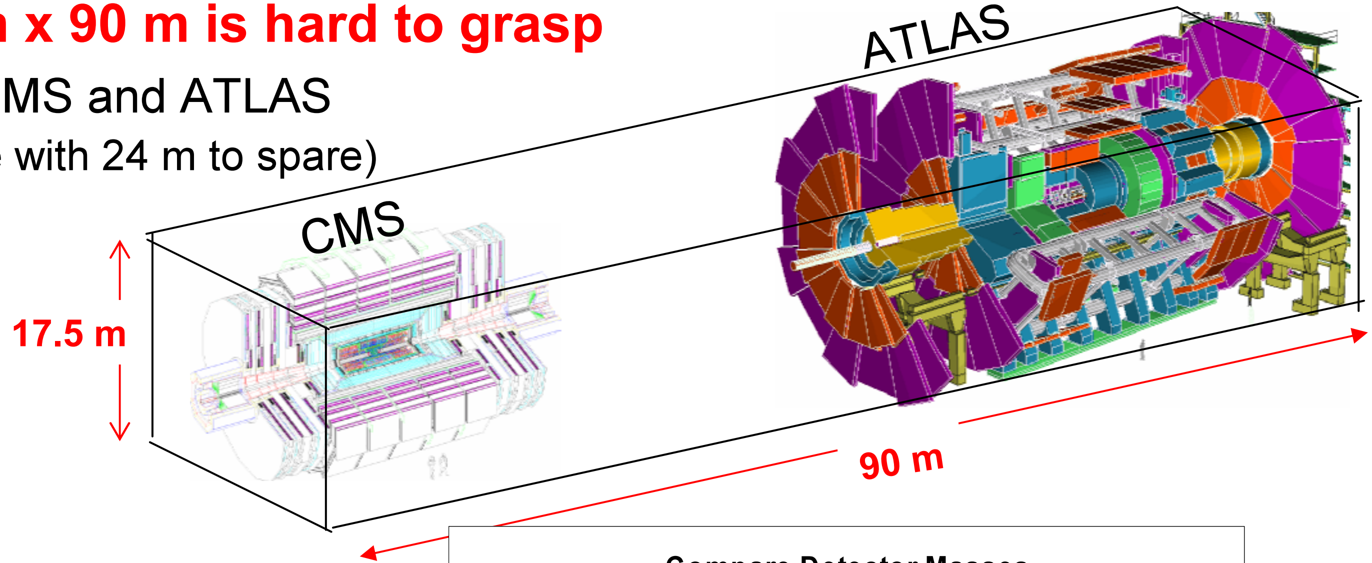


The previous plot in words:

- MINOS is 10* K2K
- **Add NOνA,** 5 * MINOS ktons
  - The Fermilab PAC believes we can compete here with T2K if we get a timely start (i.e. FY08 $ at latest, I've assumed FY07)
  - But Fermilab's budget will not support a start before FY10
  - That's one reason why we are here
- **Add a Main Injector RF upgrade**, 2 * NuMI pot
  - Allows ramp to 120 GeV in half the time
- **Add a Proton Driver,** 5 * (NuMI + MI RF) pot
  - But we don't have to decide now – see what the physics dictates
- **Add SuperNOνA,** 3 * NOνA ktons
  - Crudely driven by event rate at 2^{nd} maximum oscillation: (1/30 rate)*10*3 = 1
  - Again, consider this when we know more
- Overall, can get a factor >1000 (in 10^{20} pot * kT) in such a program compared to where we are today
  - Just like the collider program

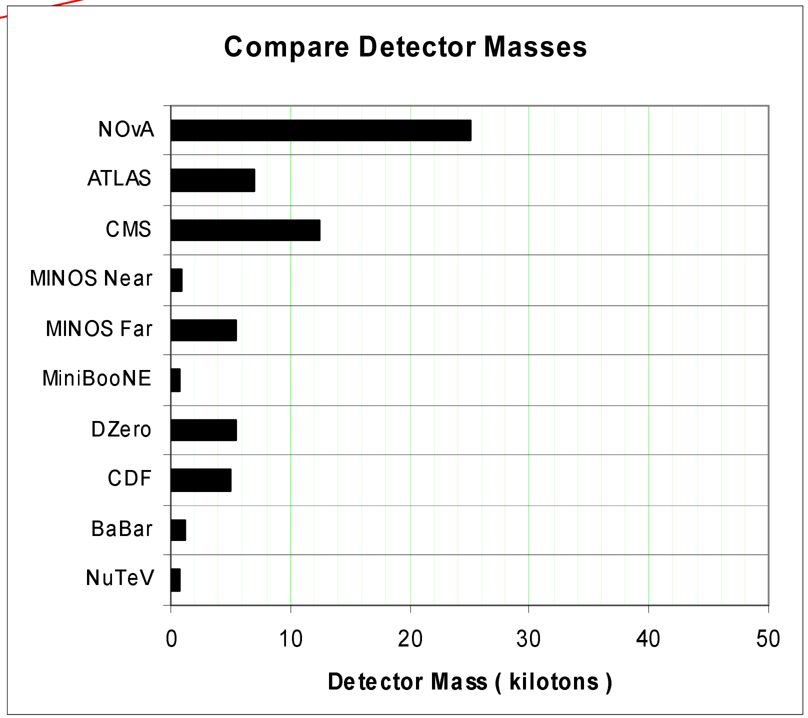
NOνA is a BIG detector

- **17.5 m x 17.5 m x 90 m is hard to grasp**
  - Compare to CMS and ATLAS
    (they fit inside with 24 m to spare)



- **25 kilotons is hard to grasp**
  - Compare to other recently constructed detectors

- **BIG because it's part of the luminosity equation, but fewer subsystems**
  - so it is possible to keep the cost low



The ATLAS cavern

Ah, but aren't colliders just richer than "measure one number" ν physics?

- **NO – While θ_{13} is the driving goal**, we should not start to think of θ_{13} like we did about the Higgs as the only justification of a program
  - Measuring θ_{13} is like finding and measuring the top mass?
  - Determining the mass hierarchy is like a Higgs discovery?
  - Detection of CP violation in the neutrino sector is like finding SUSY ?
  - **There are other physics topics**
    - Measuring $\sin^2\theta_{23}$ and $\Delta m_{23}{}^2$ at each new level of luminosity is like measuring the W mass or B lifetimes at each new level of luminosity in the collider program
    - Searching for sterile neutrino effects at each new level of luminosity is like searching for Z' at each new level of luminosity
    - Measuring low energy ν cross sections (DIS, quasi-elastic,…) is like studying QCD
    -
    -
- **There should be plenty of ν publications**

What might we learn in such a ν program?

- Something is very different between the quark and lepton sectors, so we might dream there's something major to be discovered here.
  - In the beginning of the collider program:
    - Nobody dreamed of finding a top quark of mass 175 GeV
    - They didn't really even dream of doing b-quark physics
      - » look at the CDF Design Report of 1981 – it's all about W and Z and jets
  - As with top and b-physics in the collider program, **we may not even know** what the new neutrino things are yet
    - e.g., what if MiniBooNE does see the LSND signal?
    - Whatever the unknown, will our detectors have enough flexibility to follow up when it appears? The collider detectors did.
  - **That's the excitement of this field**
  - And it is driven by pot*kT
  - despite various detector (calorimeter) types,
  - despite various detector positions of on-axis or off-axis

Summary

- **How do we get started?**
  - The Fermilab PAC indicates the start is more important than the finish
    - We need to exploit our beam while T2K has no beam
      - If we start construction in FY10, we will always play catch-up
    - There is a shortfall of in FY07 – FY10
      - AND we would put a MI RF upgrade ahead of a Proton Driver in FY07 - FY11
      - This is a shift of more $ in FY07-10 relative to the lab's current planning

- **The NuMI beam + the MINOS experiment is the on-ramp to this physics**
    - There is discovery potential and depth and breadth to such a program

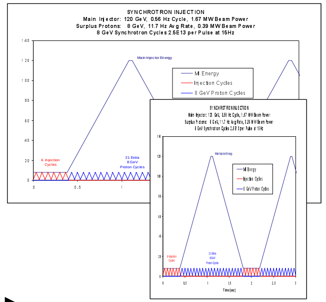
- **NOνA gets us into the fast lane**
    - A stepwise approach gives plenty of future off-ramps guided by the physics landscape
    - A partial NOνA detector does science
    - Each step of such a program does science

Understanding Neutrinos
-- a stepwise approach

2005	2009	2012	201x?	202x?

NuMI
beamline

2 *



MI RF

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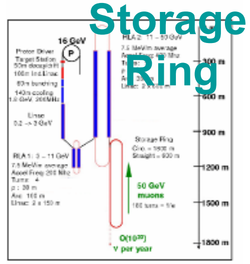
Proton Driver

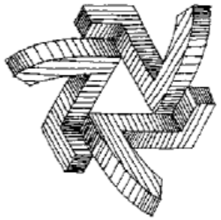
Muon Storage Ring

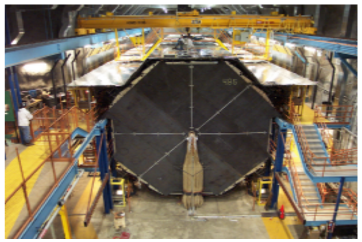


DUSEL

Different baseline

MINOS
detector





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NOvA

This is the next step

3 *

SuperNOvA

Move part of NOvA first ?

Move NOvA & SuperNOvA to new location?